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Analysis of the Behavior of Vehicle Drivers at Signal-Controlled Intersection Approach while Waiting for a Green Signal—A Case Study in Poland

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Featured Application: Behavior of drivers in a crowded state at intersections with traffic lights.

Abstract: The article presents the results of research on the behavior of vehicle drivers who, in the congested city road network (during the transport peak period), were unable to pass a traffic light-controlled intersection during one signaling cycle. They were therefore forced to wait in line at least once on the red signal before they could continue their journey. Empirical research was conducted at several intersections with traffic lights in Poland, in the cities of Bydgoszcz and Toruń. In addition, the database was supplemented with the results of surveys, which were decided to be conducted in the form of electronic form during the COVID-19 pandemic through dedicated surveys and social networking sites. The analysis of the results of field studies confirms that most drivers commit traffic offenses in the form of using mobile devices in their hands (over 60%) in the period after the start of transmitting the red signal and after stopping the vehicle. Interestingly, less than 40% of respondents admitted this offense in the survey.

Keywords: drivers' behaviors; signal-controlled intersections; traffic engineering

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1. Introduction

Traveling on transport networks by individual means of car transport has dominated our world. In most of our globe, as well as in our country, this means of transport is used in about 80% of all travel [1]. A direct measure of this is the results of cyclical measurements of the volume of road traffic, through which the increasing tendency of our mobility is learned; in the case of Poland, these trends are seen both on national and provincial roads [2,3].

The growing demand for traffic with insufficient development of the basic road network, unfortunately, accumulates the losses of travel time, and this directly affects the communication behavior of vehicle drivers. This can be seen when comparing the data on transport demand and supply. When we consider the number of motor vehicles registered in Poland (take this measure as demand), we observe an increase of over 124.9% in the years 2004–2021. On the other hand, in the case of the length of all public roads in Poland (assume this measure as the supply), in the analyzed period this increase amounts to only 13.5% [4]. Such a large disproportion must result in transport problems, although attention is drawn to a very general attitude towards the compared measures and these results reflect only a part of today's transport challenges in our country. Nevertheless, with these basic data, we can illustrate today's transport problems, which occur in large agglomerations and metropolises.

The resulting effects include, first of all, lost travel time, increased fuel consumption, increased traffic noise, vibrations, and air pollution. For example, in recent studies on the nuisance of the car transport sector for 2021 [5], which directly affects the perception of society towards obstacles to movement, it was noted that the total number of hours lost in a passenger car journey in conditions of forced traffic (traffic congestion) from one year to the next the year is growing and is currently at the level of:

- 148 h in London,
- 140 h in Paris,
- 134 h in Brussels,
- 108 h in Moscow,
- 102 h in New York,

and in Poland: 87 h in Poznań, 84 h in Wrocław, and 62 h in Warsaw. On the other hand, the data on the percentage of extension of travel time during the period of the highest demand for traffic in relation to the periods of free traffic [6], are at the level of:

- by 62% in Instanbul,
- by 61% in Moscow,
- by 56% in Kyiv,
- by 55% in Bogota,
- by 53% in Mumbai,

and in the perspective of Poland: by 45% in Łódź, by 42% in Crocow, and by 41% in Wrocław. The above lists are rankings of the most "jammed" cities in the world.

What preliminary conclusions can be drawn based on the results presented above? In the works [7–9] it was noted that the impatience of drivers has a major influence on their later behavior while driving. On the other hand, the time factor directly affects traffic conditions, including at intersections with traffic lights. Synthetically speaking, the intensity of saturation is achieved in a certain period of the green signal and follows the starting maneuver after the commencement of transmitting the red signal with the yellow one [10,11]. It is known that the reaction time (and therefore the driver's focus) has a direct impact on the quality of the level of service. One driver, distracted by external factors in their cabin (e.g., using a mobile phone) is enough to disrupt the queue unloading process, thus reducing the efficiency of vehicle service (capacity utilization) in a state of queuing at the traffic light intersection approach.For example [12], two drivers, during two consecutive signaling cycles, delaying their starting maneuver reduced the potential ability by more than half to service vehicles at a single-lane intersection inlet with traffic lights (from 17 veh./cycle to 7 veh./cycle). The effect of this disorder was such an intense extension of the so-called remaining (initial) queue of vehicles in the next signaling cycles, that with the constant value of the inflow of vehicles to the inlet of this intersection, for more than 2 h, drivers had to wait for 2–3 signal cycles more than in the case of the "normal" state runoff under undisturbed saturation conditions. The range of the vehicle queue reached the adjacent intersection with traffic lights, completely blocking the access section to the analyzed intersection approach (an example of so-called local gridlock). A side effect was also a reduction in the intensity of maneuvers of stopping in the remaining queue and starting from higher positions in the maximum back-of-queue, which had consequences on the rate of discharge of congestion from the formed queue size throughout the entire road section between two intersections [12].

The way a driver drives a vehicle is individual and consists of many factors. It depends on their level of perception, motor skills, and personal motives for action (for example, destination and hurry). These factors are also influenced by psychophysical features (e.g., eyesight, concentration), psychological features (e.g., level of intelligence, experience in driving a car), and external factors (e.g., talking on a mobile phone, passenger behavior, or consumption of alcohol and drugs). The road user is also a pedestrian, cyclist, and passenger. Passenger behavior has a marginal influence (about 0.1%) on the causes of incidents. In the research conducted by Gaspar [13], it was found that traveling with a passenger is safer because they informed about dangers that they noticed from the passenger seat and that the driver might have overlooked. Pedestrians, in turn, are the perpetrators of incidents in 3%, and cyclists in 2%, but they are often not recorded in minor road collisions. Unfortunately, the largest shareholder in the list of perpetrators is vehicle drivers [13–16]. That is why so much importance should be attached to the state of concentration during the journey.

It is presumed that it is a waste of travel time during periods of the highest transport demand (communication peak) that directly affects the desire to use a mobile phone. Realizing that time is wasted in "traffic jams", people use their mobile devices to go about their personal affairs at these moments.

The research and analyzes performed may be used to approximate the issues of transport psychology. They will also present the causes of incorrect behavior of drivers. They can also draw attention to the importance of the topic when measures are taken to improve the level of road safety.

2. Using a Mobile Phone while Traveling—Previous Research Review

The evolution of mobile devices has led to the fact that the behavior of drivers in road traffic has also changed. American research shows that driver distractions increase the likelihood of a collision. This applies to typing and reading messages, as well as chatting on a mobile phone. In the United States, a driving simulator study was conducted. The participants were twenty-four pairs of friends. One person in the pair was the driver and the other was a conversation partner in three situations: talking directly to each other in the simulator, remotely in a hands-free mode when the partner watched the drive from another room, and remotely via a mobile phone. It was compared to the driver driving alone in silence. The main problem studied was the influence of the interview conditions on the drivers' ability to avoid collisions due to unexpected events. The results of the measurements showed that the driver's distraction results, among other things, from the interlocutor's lack of awareness of what is happening on the road. The risk of a collision was reduced when the partner had visual information and they alerted the driver to unexpected events. The experiment showed that drivers using a mobile phone avoid a greater percentage of motorway exits and show worse adherence to the side lane compared to those who spoke to the passenger. Additionally, the conversation weakens the ability to notice changes while driving and to predict and slows down the reaction time of drivers [17,18].

This problem also affects truck drivers, who should keep constant contact with dispatchers. Smartphones and onboard computers contribute to their distraction on the road. In a study conducted in the United States on professional drivers using a driving simulator, it was shown that sending and reading text messages causes a total deterioration of concentration and driving efficiency. Interestingly, these studies also saw that drivers of vans who judge themselves to be very qualified drive less carefully than those who judged themselves to be qualified [15,18].

It was also noticed that new habits of the population appeared due to the development of mobile telephony, for example, reflexively unlocking the start screen to make sure about the lack of notifications. These were performed automatically. In the research of Stavrinos [18], the use of a mobile phone was analyzed in terms of habit in road traffic. Planned behavior theory was used to explain why drivers continued to use their cell phones directly while driving, despite a clear prohibition. Data analysis has shown that the use of a mobile phone increases the chances of leading to a road incident by 3.6 times. Habits of chatting, sending, reading text messages, and updating social media have been found to contribute significantly to this when driving. Moreover, drivers use their mobile phones more often when they perceive driving conditions as less demanding and safer—for example, when they stop at a red signal [17–20].

Other studies also show that passengers do not feel safe while driving when the driver uses a mobile phone. Participants in a 2015 study in the United States found that they draw drivers' attention when they hold the phone in their hand (67%) and intervene when their driver writes or reads text messages (87%) while traveling [20].

The article [21] describes the impact of using a mobile phone on the driver. Described is how it affects their behavior and distraction, translating into road safety. Field research and an internet poll were conducted. A field study found that 11.6% of 1867 drivers used a cell phone while driving, while 26.1% of the 203 drivers in the top line were using a cell phone when stopped at the traffic light intersection approach.

In the work [22], based on the results of a survey of 144 respondents, the method of using mobile phones by pedestrians and drivers were analyzed and an attempt was made to assess their impact on road safety. There was a significant percentage of drivers admitting to using a mobile phone while moving a passenger car (49% among women, 65% among men), while among pedestrians the figure was higher (86% of women and 94% of men). Cell phone use is a major cause of inattentive driving, and the driver must deal with several distractions, e.g., physical distraction is a problem when the driver takes their hand off the steering wheel to interact with the phone.

On the other hand, in the article [23], based on an online survey covering over 35,000 road users in thirty-two countries, the four most risky behaviors in road traffic were analyzed: driving under the influence of alcohol/drugs, speeding, using a mobile phone while driving, and driving when tired. The study shows that the use of mobile phones is the second most common cause of road accidents in Europe.

The paper [24] presents the results of the influence of distraction caused using a mobile phone (i.e., visual, and auditory) on the reaction time of a pedestrian to a pedestrian signal. Traffic video data was collected from four pedestrian crossings in Canada and China. The results show that pedestrian response times were longer in Canada than in China under non-distraction conditions. Distracting auditory and visual attention increases pedestrian reaction time by an average of 67% and 50%.

Remarkably interesting conclusions were drawn in the work [25]. The study investigated the relationship between self-regulation of secondary tasks and driving. The experiment consisted of taking part in a driving simulator in which participants performed secondary tasks as considered proper. The performance of thirty-five drivers aged 18–19 was assessed under three phone-use conditions, including distraction (phone-free), visual-manual, and hands-free interactions using the 'CARRS-Q' driving simulator. The results show that the degree of involvement in a secondary task affects both longitudinal and lateral control of vehicles. Drivers with a lot of hands-free interaction are more likely to choose a slower speed along a curve compared to motorways and straight sections. On the other hand, longer visual-manual interactions result in higher driving speeds. The human-machine systems approach suggests that traffic rules play an especially significant role in secondary task management as well as driving performance.

Therefore, research analyses show that the problem of using mobile devices by drivers is increasing both in Poland and around the world. The Motor Transport Institute et. al. conducted research in 2014 [26], which consisted of checking how large a percentage of drivers use a mobile phone while holding it in their hand while driving. In this research, 102,096 drivers were evaluated. It was shown that 4.1% of passenger car drivers used a mobile phone. The highest percentage was among people aged 18 to 24 (4.4%), and the smallest group was among elderly people over 60 (1.8%). Moreover, drivers use them more often in built-up areas (4.4%) than in undeveloped areas (3.6%). The share of using mobile phones driving other vehicles was greater than that of passenger cars and amounted to 5.6%. In turn, "In the public opinion poll conducted by the National Road Safety Council in 2014, when asked how often do you talk on a mobile phone while driving a car/motorcycle, as many as 64% of drivers declared that they talked appropriately: rarely (26%), sometimes (27%), often (7%) and very often (4%)". The Secretary of the National Road Safety Council repeats the opinion of international experts that holding the phone in their hand increases the likelihood of an accident because the driver is not able to hold the steering wheel firmly or change gear [26–32].

Bearing in mind the review of selected publications in popular internet portals in the field of ranking the most irritating behaviors of drivers on the roads, it can be noted that the use of a mobile phone and slow starting at traffic lights is one of the most often mentioned and one of the highest ranked abnormal behaviors. Hence, it can be concluded that in addition to the actual impact on the capacity of the lane at the crossing with traffic lights, these behaviors may also give rise to a factor that increases the risk in road traffic due to the growing nervousness of vehicle drivers behind the driver using the telephone, calling their distraction, unnecessary disturbance in the smooth flow of vehicle streams.

3. Own Survey and Field Research Design

The survey was conducted online using the Facebook social network in various subgroups of social groups in 2020 and 2021. The survey had twenty questions, including nineteen closed questions (14 single and 5 multiple choices) and 1 open question. The survey aimed to find out about the behavior of drivers and whether it influences the functioning of traffic. 1509 people participated in the study. The questions were addressed to drivers about their behavior while waiting for a green signal at the intersection entrance or while traveling by car unless, it was mentioned that they are in a different situation (e.g., as a passenger).

In the research, 57% of people were women and 43% were men. Most respondents were people aged 18–24 (63%), then in the age group 25–50 (35%), while older people constituted the rest of the respondents (51–70 years 1% and over 70 years also 1%). If the respondents hold a driving license, the results are as follows:

- less than 2 years—14%,
- from 3 to 5 years—48%,
- from 6 to 10 years—21%,
- from 11 to 20 years—11%,
- over 20 years—6%.

Based on the above, it can be concluded that most respondents were people with the least experience in road traffic (the so-called "young drivers").

The vast majority of the respondents attributed themselves to the group of people "feeling confident behind the wheel" (55% feeling comfortable in road traffic, 39% feeling rather at ease), while the remaining group of respondents was represented by people driving the vehicle less confidently (3% feel rather uncomfortable, although they drive a vehicle often, and 3% find driving inconvenient because they rarely move as drivers).

In turn, field studies were conducted in Bydgoszcz and Toruń at a total of 5 inlets of large intersections with traffic lights (intersections of main roads with an inter-district or transit function). The test site was selected in such a way that the person taking the measurements had the freedom to observe the intersection entrance from the position of the lane dividing the road (tram stop platform). Each inlet was distributed at 3 h of observation during the peak hours of 2:00 p.m.–5:00 p.m. on typical working days. The field tests were conducted by observing the behavior of drivers at the inlet in the period after the start of transmitting the red signal for the first ~10 s after stopping the vehicle.

The field tests showed the behavior of 2195 drivers and the performance of various activities in the initial phase of waiting for a green signal. The research method was the direct observation of the behavior of drivers in the vicinity of the intersection entrance, without informing vehicle drivers about this fact, to reflect the "nature" of drivers' behavior as closely as possible. There are several types of behavior expected: using the phone (holding it in your hand), talking on the phone (holding it in your hand to your ear), talking on the phone (hands-free), drinking, eating, smoking, using headphones in your ears, and using the phone on the mount. These behaviors took place at each of the examined intersections in every single hour of observation. Additionally, other activities performed by drivers of vehicles were observed, the results of which were grouped separately.

4. Results of Surveys

One of the first questions asked by the respondents was the knowledge of the provisions of the Road Traffic Law about the use of a mobile phone while transmitting a red signal (waiting for a signal that allows traffic). 56% of the respondents gave an affirmative answer: the driver must not perform this activity without a headset, 29% of them were convinced that this behavior is not inconsistent with applicable regulations, while 15% were unable to answer (marked "I don't know"). The next question was a request to state the frequency of using a mobile phone while traveling by car. The results obtained are as follows:

- always—7%,
- often—21%,
- from time to time—26%,
- rarely—38%,
- never—8%.

It is noteworthy that although over 50% of the information about the current ban on using the telephone while driving was found, over 90% of the respondents declared that they would perform this activity while traveling.

Then, the respondents were to supply the manner of using the telephone by the respondents in case of stopping the vehicle at the intersection entrance while waiting for a green signal. The respondents said that the mobile phone they use in such a situation is:

- mounted on a special holder—55%,
- hand-held—40%,

or otherwise used—5% (e.g., smartwatch worn on the wrist or steering wheel).

The main reasons for using a mobile phone while traveling in a motor vehicle, given by the respondents, are presented in Figures 1 and 2—as a driver or as a passenger, respectively. The most frequently chosen responses among those mentioned by drivers were: continuation/starting a voice call (57.65%), changing music (48.53%), and replying/starting SMS (34.97%). Much fewer people say that they use a telephone to enter voice commands (15.52%) and search for information (8.84%). A slight percentage of the respondents chose to read the content of mobile media (3.14%), look at the status of other social profiles (2.95%), watch a movie/series (1.38%) or play (0.98%). Only one person listed making/continuing online purchases and updating status on a social networking site. Moreover, 12.38% of the respondents replied other, of which the use of navigation accounted for approximately 90% of these responses.

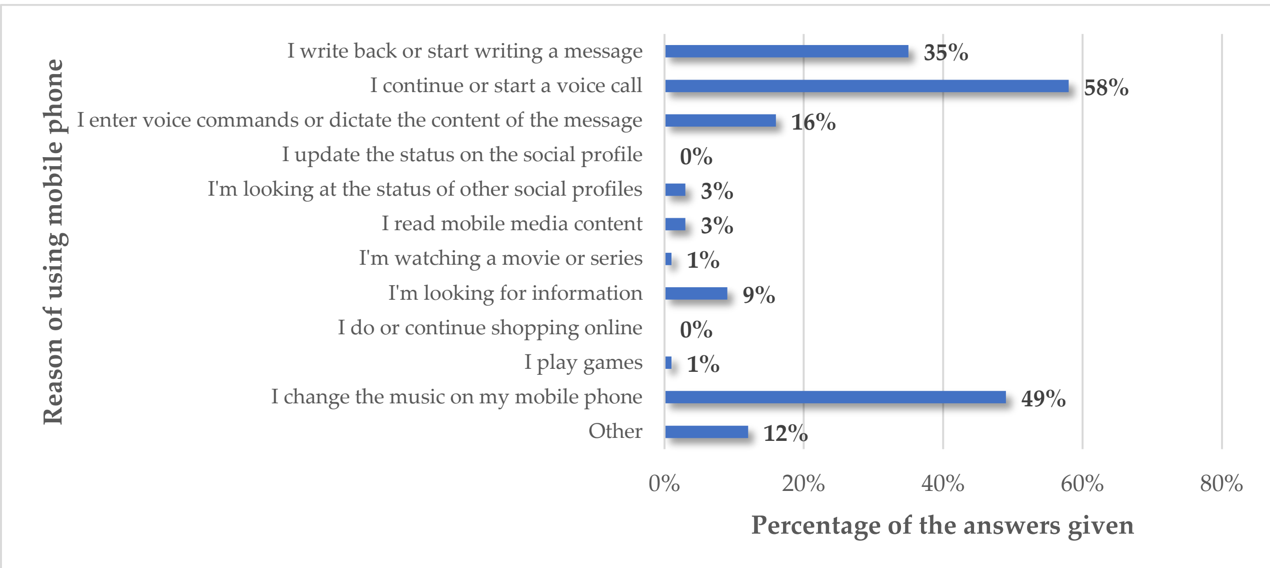

Figure 1. Typical purposes of using the phone as a driver while traveling.

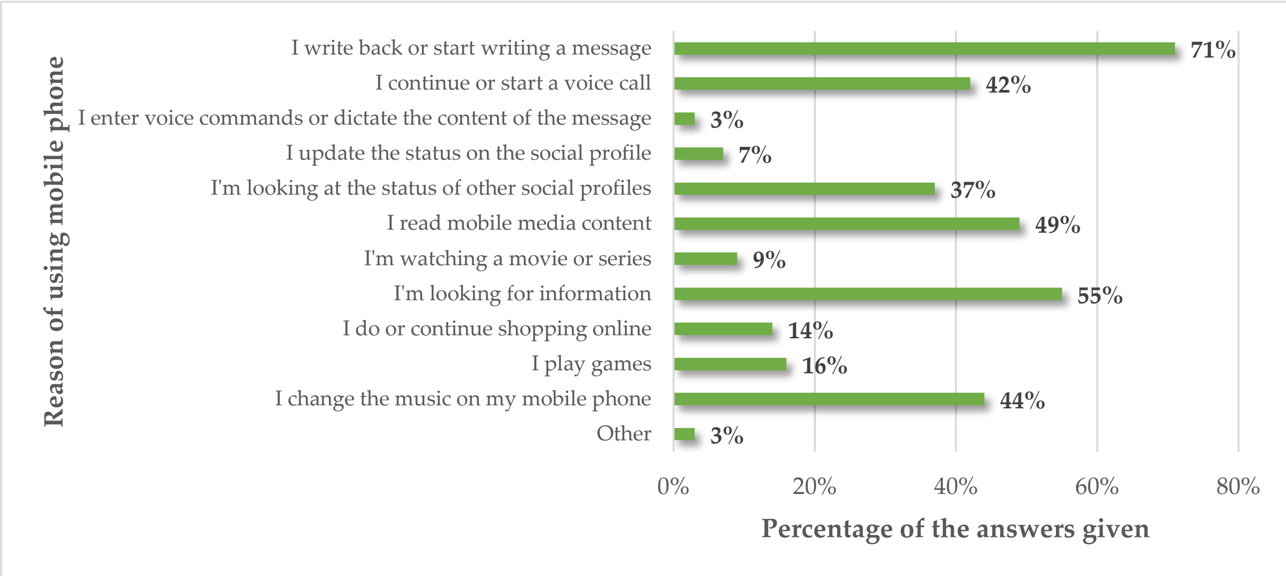

Figure 2. Typical purposes of using the telephone as a passenger while traveling.

The indicated reasons for using the telephone during the journey as a passenger are presented in Figure 2. Most people believe that they use the telephone to reply/start texting (71.12%). In turn, more than half of the respondents "simply" look for information (55.21%) and read the content of mobile media (49.31%). Almost half of the people said that they change their music (43.61%), continue/start a voice conversation (42.24%), and look at the status of other people on social networks (37.13%). About 15% of respondents say that they use a phone to play games and continue shopping online. The smallest percentage of respondents chose to update their status on a social networking site (7.47%), watch a movie/series (8.64%), and enter/continue voice commands (3.34%). Moreover, 1.18% of the respondents replied other, of which the use of navigation accounted for almost 90% of these responses. The rest of the respondents use the telephone to check the time.

Figure 3 shows the purposes of using a mobile phone by drivers, but only during the waiting period for a green signal at the entrance to the traffic light intersection. The responses supplied show that the most often performed activity by drivers is texting them (51.47%). Next is changing the music (40.47%) and continuing/starting a voice conversation (37.33%). A much smaller percentage of respondents is looking for information (10.61%), introducing voice commands (8.84%), looking at the status of other people on social networks (6.68%), and reading electronic media content (5.50%). Only 1.38% of respondents use mobile games, 0.59% update their status on a social network, and 0.79% do/continue online shopping. Only one person said that they were watching a movie/series at that time. In addition, 4.13% of the respondents replied other, of which the use of navigation accounted for approximately 85% of these responses. The rest of the respondents use the phone to check the time or e-mail.

The analysis highlighted one of the activities showed by the respondents often, namely "changing music" (over 48% while traveling and over 40% while waiting for a green signal). This activity raises serious concerns in today's use of a vehicle equipped with a stationary radio. It is visible how the development of streaming services (access to the selected soundtrack via the Internet from the position of a mobile device) affects the transport behavior of drivers and passengers. It can be guessed that these activities are performed by young people who interact with a newer generation telephone daily.

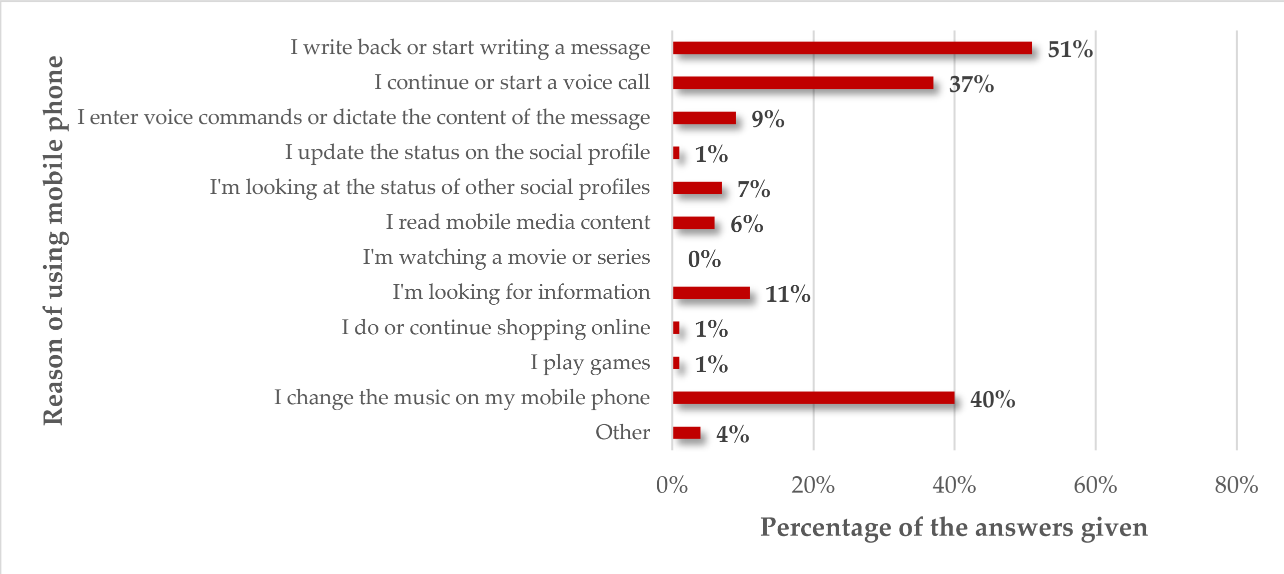

Figure 3. Typical goals of using a telephone as a driver while waiting for a green signal.

The aim of the research was also to obtain information from respondents on the self-assessment of their behavior and, from their perspective, its impact on road safety. Hence the questionnaire was asked how often they looked at the status of the sequence of light signals emitted by the beacon during the period of using the mobile phone (to make sure that the green signal period had not already begun). As many as 87.93% of respondents declare that they "take their eyes off" the screen every few seconds. A much smaller percentage of people do it every ~10 s (7.54%). In the case of a longer range of time, 1.51% of the respondents declared this answer every 11–20 s, while at over 20 s this represented 3.02% of them.

Then the question was asked whether using mobile devices while waiting for the green signal poses a threat to road traffic for the other road users. It turns out that less than half of the answers given (47.90%) show that there is no such threat. Slightly less, 43.31% say that using mobile devices while waiting for a green signal is dangerous. Almost 9% of people admitted that they cannot answer this question (by answering "I don't know").

The survey participants were also asked whether they had ever "missed" due to the use of mobile devices while waiting for a green signal. More than half of the respondents (57.17%) did not have such circumstances. In turn, nearly 40% stated that they had missed (late with the starting maneuver), but this situation is rare. Only 3.14% of people, when answering this question in the affirmative, also said that they were in such a situation often.

In terms of road safety, two additional questions were also asked which are not related to the use of a mobile phone. When asked: "how often do you observe the siren while waiting for a green signal", most respondents said that they looked "every now and then" (72.50%). Out of the total share of answers provided, the second was "I try all the time" (18.47%). The remaining responses were a small percentage, i.e., "when stopping, starting and leaving the intersection" (5.11%), "only when arriving, and then I observe the vehicles standing in front of me and then I make sure" (2.95%) and "only when stopping and starting" (0.98%). The second question was the interest in traffic conditions at the intersection itself. Most respondents (64.24%) said that they pay attention to what is happening at the intersection all the time. One-third said that they are sometimes distracted by other situations. Only 4.72% focus their attention only after turning on the green signal on the signaling device to which the light signals refer.

The last questionnaire was an open-ended question: "what else do you happen to do while waiting for the green signal?". The most common responses were talking with a passenger (almost 58%), singing or humming (almost 28%), tapping or tapping with your hands (slightly over 18%), thinking (almost 16%), or planning (over 10%). All the obtained responses, properly grouped, are presented in Figure 4.

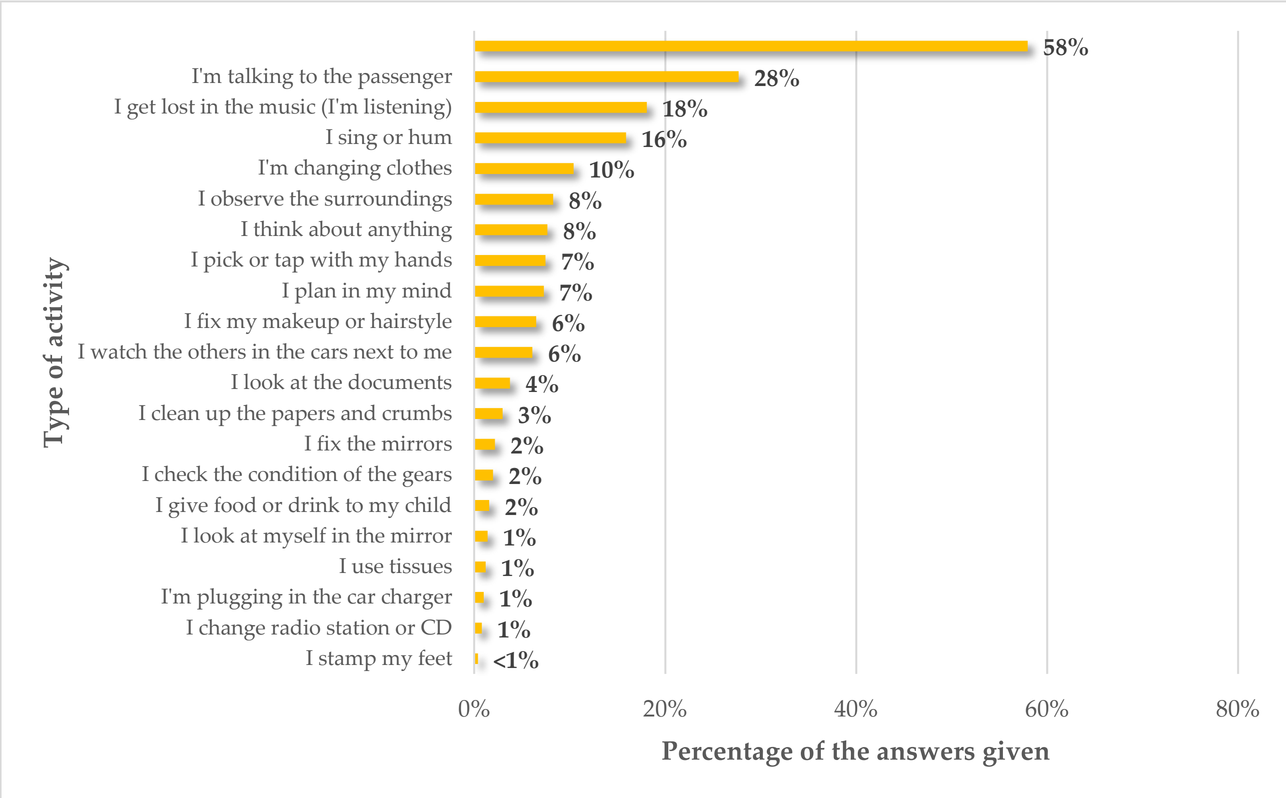

Figure 4. Other activities that drivers perform while waiting for the green signal.

Statistical significance was analyzed for various groups of people in terms of sex and age group. Due to the small number of responses in the group of respondents aged over 70, their results were combined with the group aged 50–70. The statistical analysis was performed with the Kolmogorov–Smirnov lambda test. The distribution of the obtained responses in individual groups of people was compared, at the alpha significance level of 5%.

With such selected assumptions, it turns out that:

1. there are significant statistical differences in the way of using a mobile phone between women and men;
2. there are no significant statistical differences in the way of using a mobile phone between the age group of 18–24 and 25–50, but there are significant differences between these groups compared to the oldest group of people (over 50);
3. there are significant statistical differences in the reasons for the use of a mobile phone by drivers between men and women and between the youngest group of people (aged 18–24) and the rest, but there are no significant statistical differences between the group of people aged 25–50 and over 50 years of age;
4. there are significant statistical differences in the reasons for the use of a mobile phone by passengers for travel between all groups of people, broken down by gender and age;
5. there are significant statistical differences in the reasons for using a mobile phone at once after stopping at a red-light signal interval between all surveyed groups of people, except for the groups of people aged 25–50 and over 50.

The main difference between men and women in the manner of use mobile devices is that men more often use a mobile phone attached to a special holder, and women more often use a mobile phone in their hand. In the case of the reasons for using a mobile phone when the driver is a woman, the main difference compared to men is primarily a much smaller percentage of women who change music and look for information via a mobile phone. In the case where a woman is a passenger, the main difference is the much greater share of using a mobile phone to look at the status of other social profiles and to read mobile media content in relation to male passengers. Men, as passengers, play more on their mobile phones. In the case of differences between a woman and a man who wait for a green signal in the car, more men change the music on the mobile phone than women, and women more often continue or start a voice call on the mobile phone than men.

In the case of differences noted in individual age groups of respondents, young drivers using a mobile phone while traveling much more often reply to or start a new text message and change the music using a mobile phone more often. However, what is quite surprising is that they continue or start a voice call using a mobile phone less frequently than older drivers. In the case of differences noted in individual age groups of respondents, young drivers using a mobile phone while traveling much more often reply to or start a new text message and change the music using a mobile phone more often. However, what is quite surprising, they continue or start a voice call using a mobile phone from older drivers less frequently. In individual age groups, people who are passengers behave in a statistically significant, different way from each other. The main differences result from the frequency of voice calls, replying to SMS messages, looking at social media profile, and playing and changing music. In individual groups of people in terms of their age, only young drivers, compared to the older and the oldest ones, use the mobile phone differently while waiting for the green signal. The main differences are:

- more frequent texting,
- less frequent voice calls,
- definitely more frequent changes of music.

5. Results of Field Observations

All the observed behaviors of drivers who waited in the queue after stopping for the commencement of transmitting a green signal, expected in the tests, are illustrated in Figure 5. It turns out that on average, more than 73% of drivers used mobile devices in several ways for up to 10 s after stopping. Worryingly, 55% of them were using the phone in their hand (while looking at the screen), and 9% were talking with the phone close to their ear. In addition, 3% of people were seen using a hands-free kit, the same percentage was for people using headphones in their ears, and almost 4% of people used the phone on the mount. This means that 64% of drivers committed an offense. At individual intersection entrances, the highest percentages of abnormal behavior concerned the driver using the phone in their hand and they were:

1. the intersection of Plac Daszyńskiego (Szosa Lubicka Street, Trasa Wschodnia Street, Żółkiewskiego Street), Toruń, eastern approach—48%,
2. the intersection of Fordońska Street, Łęczycka Street and Kazimierza Wielkiego Street, Bydgoszcz, west approach—48%,
3. the intersection of Szosa Okrężna Street and Bronikowskiego Street, Toruń, eastern approach—56%,
4. the intersection of Rondo Fordońskie (Fordońska Street, Jagiellońska Street and Wyszyńskiego Street), Bydgoszcz, eastern approach—58%,
5. the intersection of Rondo Toruńskie (Toruńska Street and Wyszyńskiego Street), Bydgoszcz, eastern approach—62%.

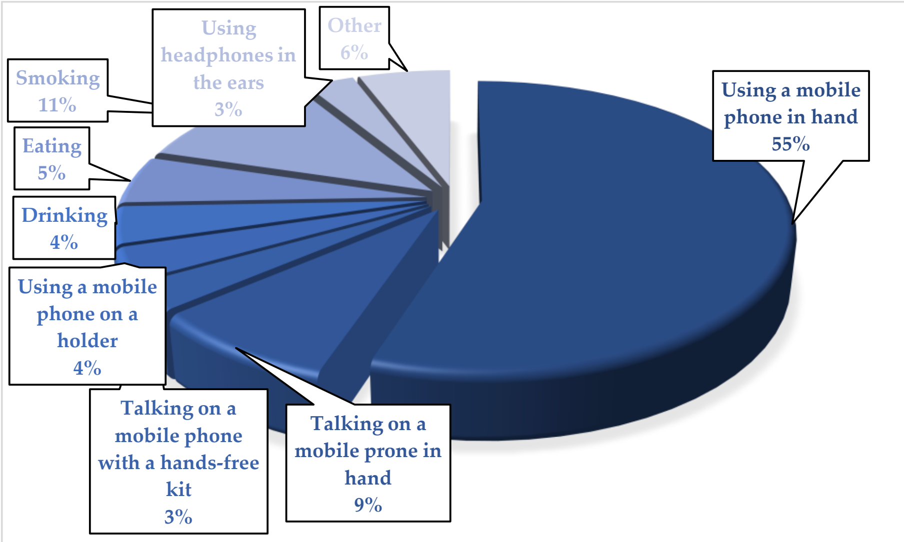

Figure 5. The results of the research on the expected behavior of vehicle drivers in the period after stopping due to the commencement of transmitting a red signal.

It is noted that this was the behavior of drivers shortly after making the stopping maneuver to wait for the commencement of transmitting a green signal. This means that drivers are fully aware that their stopping at the traffic light intersection will take a long time, allowing them, "in their opinion", to use this period to use a mobile device. The most frequently performed other activities while waiting for the green signal include viewing documents and correcting hairstyles or make-up.

A statistical test of the Kolmogorov–Smirnov lambda concordance was performed to detect significant differences between the tested proving grounds for a significance level of 5%. On its basis, there was only one case where the results differed from each other in terms of statistical significance, and it was between intersection numbers 1 and 4. The difference in this case between the computational p-value (1.549) and the critical p value (1.358) is estimated at little. In other cases of comparisons, the critical p value was not exceeded.

The comparison of undesirable behaviors of vehicle drivers while waiting for the green signal is presented in Table 1. It turns out that:

- there was a much higher percentage of people using a mobile phone while waiting for a green signal in questionnaire surveys than in field observations; there were significantly more cases in field observations of offenses involving the use of mobile phones in the hand of drivers in a stopped vehicle.

Table 1. Comparison of the results of questionnaire and empirical research in the case of using a mobile phone.

Type of Behavior of the Vehicle Driver after Stopping at the Signal-Controlled Intersection Approach in the Initial Phase of Starting Red Signal Interval (Waiting for a Green Signal)	Percentage of Drivers [%]	
	Survey Research:	Field Research:
Using a mobile phone in any way	91.55	73.32
Using a mobile phone in hand	39.69	63.72
Using a mobile phone on a holder	55.40	3.56
Any other use of the mobile phone (e.g., headphones, smartwatches, etc.)	16.50	6.04

6. Discussion and Conclusions

The primary purpose of the work was to learn about the behavior of drivers at the intersection entrance while waiting for a green signal. The questionnaire and field studies confirmed the expected behavior but also allowed learning about other activities performed by drivers and expanded knowledge on this subject.

Nowadays, mobile devices, mainly mobile phones, are common. The evolution of smartphones has led to the fact that drivers' behavior on the roads is also changing, which affects their level of attention during the journey. Despite widespread media coverage, and laws prohibiting certain forms of mobile phone use, and while technological developments allow them to be seen in several ways, for example using surveillance or speed cameras, drivers still make extensive use of them. The survey showed that around 90% of drivers admit to using their mobile phones to a greater or lesser extent while traveling, and over 27% of them say that they do so often or always. Moreover, almost 40% of respondents hold a phone while driving a car.

Based on the results, it was possible to diagnose the main reasons for the use of mobile phones, both by drivers and passengers of individual car transport. The reasons for using mobile phones while traveling have not been studied in such detail so far. Drivers most often use the phone to continue or start voice calls when traveling by car. However, when they stopped at an intersection while waiting for a green signal, the reason for using the phone changed. Most often drivers use this moment to write back or start a new text message. One of the more interesting results is that, apart from the expected use of the phone for a conversation or for writing messages, a significant percentage of activities related to changing music with this device. In both cases (while driving or stopping), drivers admit to using the phone to change the music (~48% while driving and ~40% while waiting for a green signal).

Driver distraction is one of the most common factors leading to a collision, as shown in the literature review. Interestingly, the most dangerous factor turns out to be writing or reading SMS messages, followed by a phone call. The obtained research results show that the driver most often continues or starts a conversation or changes the music using the phone, but more than one-third of the respondents said that they were using them to send SMS messages.

When waiting for a green signal at the intersection entrance, drivers will admit to using a mobile phone to start/write a text message, change music or continue or start a voice call. In addition, half of the respondents believe that they do not pose a threat to traffic while waiting at the intersection with traffic lights while performing these activities. The results of the field research slightly changed the context of the (internet) survey results, as there was a slightly smaller, but still large (over 73%) percentage of people who first start using a mobile phone or other mobile devices after stopping at the red signal. It should be noted that over 63% of the observations concerned the use of a telephone set directly with the hands, which is prohibited under the current regulations in Poland and is an offense.

In addition to using a cell phone, drivers engage in several distracting behaviors. The most common ones are smoking, eating meals, using other mobile devices, correcting makeup, viewing documents, talking to a passenger, singing, watching other drivers or passengers, contemplating, or tapping with your hands. Another crucial factor in distracting attention is the conversation with the passenger. It is also worrying that 43.6% of respondents openly admitted that they do not know or are not aware of the provisions of the Road Traffic Law in the field of the use of mobile devices.

In the case of passengers, a much greater number and frequency of indications of the reasons for using mobile devices were noticed. The drivers rather unambiguously defined the reasons commonly considered "typical", i.e., voice conversation (58%) and writing messages (35%), and also the unexpected reason—"changing music" (49%). On the other hand, passengers showed mainly writing messages (77%)—which is more than twice the share of indications than the case of drivers. Then were the categories of looking for information (61%), reading electronic media (55%) and changing music (same as drivers—49%). Voice conversation was indicated in a smaller percentage than in the case of drivers (48%). It is visible here how much the attention of passengers is absorbed by activities performed with the use of mobile devices during the journey, and how big the difference is in the reasons for using the telephone during the journey between the driver and the passenger.

It was also noted that the results of this study differ slightly from the observations in [21]. In the author's research at the test ground, in which the behavior of all drivers stopping in the queue was seen, almost 40% of the use of the telephone was found. Research [21] showed that the share of such drivers (~26%) was lower by half. However, it is stipulated that only vehicles from the beginning of the forming queue of vehicles were evaluated in this study.

Bearing in mind road safety, the phenomenon under study should be assessed negatively. Being a driver of a vehicle stopped in the queue at the entrance to the intersection, one should foresee the necessity of higher importance, for example, to give way to vehicles of emergency services, creating a corridor of life. When distracted, e.g., due to the use of a mobile phone, emergency services lose precious seconds spent on reaching injured persons or places where life and property are at risk. Hence, the importance of this problem is of high importance, which should be examined more closely and reach the awareness of drivers, informing them about the possible consequences of this incorrect behavior on the road. This also applies to the entry of intersections with traffic lights, where most of us wait in line during peak times. As confirmed by other studies, it is the waiting time in the queue that irritates vehicle drivers the most, influencing their level of stress during the journey. The use of mobile devices while waiting for a green signal is related to the reduction of the level of this unfavorable factor for our body or, by devoting this lost time to other matters not related to road traffic, at least this is authors belief.

In this regard, it is recommended to conduct in-depth research in the field of transport psychology. It is believed that the results of this study may prompt a more detailed understanding of the problem of drivers' lack of concentration on the roads. Based on these research results, those responsible for improving road safety can specify further actions to minimize the risk caused by the undesirable use of mobile devices when traveling by car.

The authors want to emphasize that the presented research results are based on a simple online survey method. Their results were later subjected to other verification through field observations. The survey aimed to obtain unambiguous reasons and frequency for using mobile phones while traveling among drivers waiting for a green signal at intersections with traffic lights. The aim of the field observations made was to check whether the results of the questionnaire surveys are correct. Due to the difficulties of empirical research, the observation time of a single driver was limited to only 10 s immediately after stopping in the queue of vehicles. Despite such an abbreviated time of observation, remarkably interesting data was obtained, which clearly shows what drivers do immediately after stopping while waiting for the possibility of further driving. The authors are aware of the limitations resulting from the research performed. For obvious reasons and technical problems of continuous observation of the driver population in congested cities, this method of research was considered sufficient. The road users subjected to the study were not informed about this fact, nor were they registered with video devices.

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